# Verified Ammonia Carbon Intensity

## Ammonia
## Carbon Intensity Calculation Methodology

VERIFIED AMMONIA
CARBON INTENSITY

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# REVISION HISTORY

| | | | | |
|---|---|---|---|---|
| **Revision Date** | **Description** | **Sections Affected** | **Revised By** | **Approved By** |
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# 1 Introduction

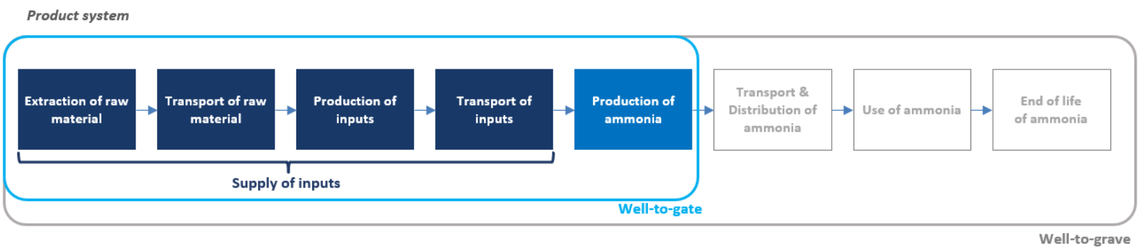
This document specifies the methodology to be applied to calculate the ammonia carbon intensity (CI).

# 2 Scope

The procedures described herein verify production claims for low-carbon ammonia. The scope of the carbon intensity calculation within this calculation methodology is well-to-gate. The emissions from the extraction of the raw materials up to the production gate of ammonia production must be accounted for in the carbon intensity of ammonia. Downstream emissions resulting from the transportation of ammonia may be optionally disclosed. Emissions from the construction of assets in the product system are excluded. The emissions occurring from the extraction of the raw materials up to the production gate of ammonia production must be accounted for in the carbon intensity of ammonia. The processes within the product system included in the CI calculation scope are depicted in Figure 1. Emissions from the transport and use of ammonia and the product end-of-life are not considered.

The system boundary shall include all the production stages needed to produce liquid ammonia at atmospheric pressure.

*Figure 1: Scope of carbon intensity calculation*




The greenhouse gas emissions to be considered are $CO_2$, methane ($CH_4$), and nitrous oxide ($N_2O$), applying the following $CO_2$ equivalence factors for a 100-year time horizon as established in the Sixth Assessment Report by the Intergovernmental Panel on Climate Change[1].

- Methane: 28
- Nitrous oxide: 273

[1] Intergovernmental Panel on Climate Change: *Sixth Assessment Report*; 2022.

# 3 Definition of Terms

*Table 1: Definition of Terms*

| Term | Definition |
|---|---|
| Carbon intensity (CI) | The quantity of GHG emissions and removals of a product, expressed in Mt $CO_2$ equivalents/Mt. |
| Carbon Capture and Storage (CCS) | CCS is a process in which a relatively pure stream of carbon dioxide ($CO_2$) from industrial and energy-related sources is captured, conditioned, compressed and transported to a storage location for long-term isolation from the atmosphere. |
| Carbon Capture and Utilization (CCU) | CCU refers to a range of applications through which $CO_2$ is captured and used either directly (i.e., not chemically altered) or indirectly (i.e., transformed) into various products. |
| Core Energy Input | Energy input contributing to the energy content of ammonia. |
| Enhanced Oil Recovery | Refers to the process of extracting oil from a well through the forceful injection of $CO_2$ gas to extract oil once primary and secondary recovery is exhausted. A share of the $CO_2$ remains in the well and can be considered permanently stored. |
| Heating Value | The amount of heat released during the combustion of a specified amount of a substance, usually a fuel. Also called the calorific value, it is a physical property of each substance. It is measured and expressed in units of energy per unit of the substance, e.g., kcal/kg or kJ/kg. |
| Higher Heating Value (HHV) | The higher heating value, or gross heating value, is the amount of heat released when a fuel is completely burned, and the combustion products are cooled to the initial temperature of the fuel and the water produced has condensed to a liquid state. |
| Lower (Net) Heating Value (LHV) | The lower heating value, or net heating value, is determined by subtracting the heat of vaporization of the water vapor from the higher heating value. This method treats any water formed as vapor. The energy required to vaporize the water therefore is not realized as heat. |
| Natural Gas (NG) | A combustible, gaseous hydrocarbon fossil-fuel mainly composed of methane ($CH_4$) used for heating, power generation and other industrial applications. |

| | |
|---|---|
| Renewable Energy Certificates (RECs) | Market-based instrument that represents the property rights to the environmental, social, and other non-power attributes of renewable electricity generation. |
| Renewable Natural Gas (RNG) | Anaerobically generated biogas that has been refined for use in place of fossil natural gas. Biogas can be sourced from municipal solid waste, landfills, wastewater treatment plants, stand-alone organic waste management operations, and livestock manure management systems. |
| Residual mix | Refers to the remaining electricity supply mix available to consumers after Renewable Energy Certificates are accounted for. |
| Responsibly Sourced Gas (RSG) | Natural gas extracted and processed through operations that meet certain environmental, social and governance (ESG) standards, verified by an independent third party. |
| Well-to-gate CI | Partial lifecycle carbon intensity of a product considering all the processes in the product system from extraction of raw materials to the point where the product is made available for transport and supply to users, expressed in Mt $CO_2$ equivalents/Mt. |
| Well-to-supply-gate CI | Partial lifecycle carbon intensity of a product considering all the processes in the product system from extraction of raw materials, transport to the user of ammonia up to the supply of ammonia to the user, expressed in Mt $CO_2$ equivalents/Mt. |

# 4 Calculation of the Carbon intensity of Ammonia

## 4.1 General Calculation Approach

The calculation of the carbon intensity of ammonia shall follow the methodology defined by standard ISO 14067 *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification*.

The carbon intensity is the sum of greenhouse gas (GHG) emissions and GHG removals across the considered lifecycle scope per unit amount of product, expressed as $CO_2$ equivalents ($CO_2e$).

It is calculated by dividing the net sum of GHG emissions across the considered lifecycle scope for the amount of ammonia produced in the assessed period by that amount of product.

$$CI = \frac{E}{N}$$

| | |
|---|---|
| $CI$ | carbon intensity of ammonia (Mt $CO_2e$/Mt), |
| $E$ | lifecycle GHG emissions for the amount of ammonia produced in the assessed period (Mt $CO_2e$), |
| $N$ | amount of ammonia produced (Mt), |

## 4.2 Quantification of Lifecycle Emissions

The lifecycle emissions in the assessed period are quantified by adding up the emissions from the various segments of the supply chain:

$$E = e_{input} + e_{process} - e_{CCS}$$

where

| | |
|---|---|
| $e_{input}$ | emissions from supply of inputs (Mt $CO_2e$), i.e., the well to supply gate emissions related to the inputs |
| $e_{process}$[2] | emissions from the production of ammonia from the above inputs (Mt $CO_2e$), |
| $e_{CCS}$ | net emission savings from carbon capture and long-term geological storage (Mt $CO_2e$). |

Possible GHG emissions from use of the ammonia (such as emissions of nitrous oxide) are not included since these take place beyond the point of supply.

Since ammonia production requires all the carbon contained in the inputs to be oxidized, emissions from supply of inputs and their processing may be

[2] $e_{process}$ is inclusive of process $CO_2$ and combustion $CO_2$ emissions

quantified in a single step by considering the emission factor of the inputs multiplied by input quantity.

Non-$CO_2$ GHG emissions from the ammonia production process need to be quantified (in $CO_2$ equivalent emissions) and added to the calculation.

### 4.3 Concept of Core Energy Sources

The origin of ammonia identifies the core source of the energy used to produce ammonia, referred to as core energy input. The concept of core energy input is based on determining which energy input is used to generate the ammonia molecules composing the ammonia product, thereby contributing to its energy content, as reflected by its lower heating value.

Core energy input is defined as follows: *Energy input contributing to the energy content of the ammonia.*

According to this definition, the core energy input in ammonia production is the energy content of the hydrogen consumed in the ammonia synthesis process. Any ancillary energy consumption does not contribute to the energy content of ammonia and is therefore not a core energy input. The ammonia CI calculation applies the concept of core energy inputs by assigning an ammonia CI value corresponding to each core energy input.

### 4.4 Steam Emissions Calculations

All steam imports and exports, i.e., process steam, steam for drivers and heating steam, are included in the calculation of the ammonia CI. Steam imports and exports are based on their actual enthalpy at the plant system boundary. Export steam must have a verified use for it to result in emissions savings (credit). Vented steam and other such uses (e.g., condensed steam with no work output) do not qualify as export steam and do not qualify for an emission credit.

The energy of the steam is calculated as the enthalpy required to generate that steam at conditions consistent with the plant design. This can include:

- From saturated water at 15 °C in a 90% efficient natural gas boiler (a conversion efficiency of 90% LHV is typical of plant steam boilers) or;
- From saturated water at 15 °C in a 98% efficient heat exchanger from natural gas (a conversion efficiency of 98% LHV is typical of a plants waste heat boilers).

The steam's carbon intensity is determined by converting the required energy, to an equivalent basis in terms of natural gas or hydrogen, and then translating this equivalent into emissions using an acceptable emissions factor.

Plants have the option of using their actual generation efficiencies in cases where they significantly differ from the above-mentioned default conversion efficiencies.

### 4.5 Ammonia Storage

The energy related to product storage, such as refrigeration, and handling falls outside the system boundary and thus, no adjustments are made to account for this energy in the calculations. However, there is an exception in cases where vapors from refrigerated ammonia storage tanks are directed back to the ammonia plant for compression and condensation. In these instances, the energy used is not excluded from the calculations.

### 4.6 CI Calculation Based on Production Configurations

The CI calculation methods, as they relate to different production configurations, are described below. These methods increase in complexity depending on the number of co-products and the range of energy sources that contribute to core energy inputs.

## Ammonia From a Single Core Energy Source

When ammonia is produced without any by-products such as steam, and all the hydrogen used in the production process is derived from the same core energy source, then the ammonia carbon intensity can be determined using the method illustrated in Figure 2.

As stated in section 4.2, since ammonia production requires all the carbon contained in the inputs to be oxidized, emissions from supply of inputs and their processing may be quantified in a single step by considering the emission factor of the inputs multiplied by input quantity.

*Figure 2: Calculation of the carbon intensity of ammonia from a single core energy source*

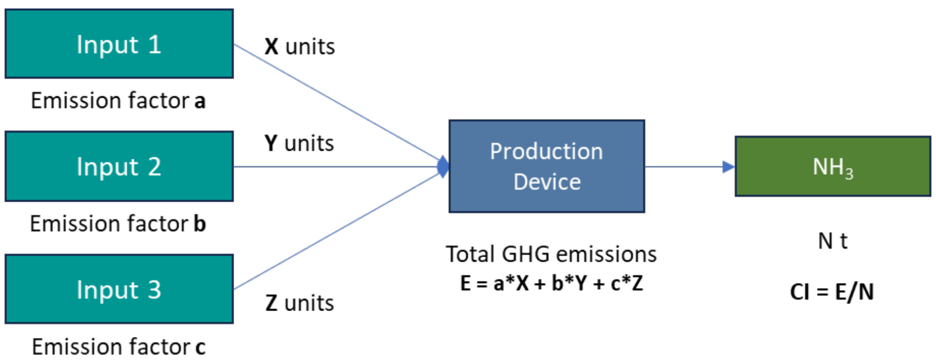
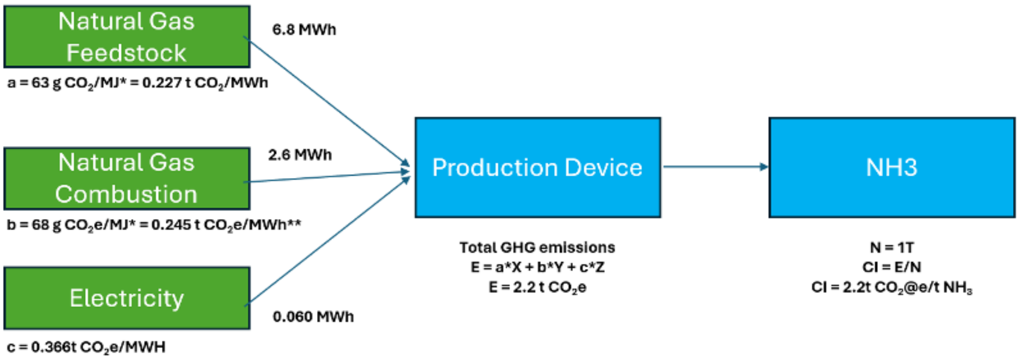


*Figure 3 Illustrative example of CI calculation for 1 ton of ammonia*




*Emission factor of natural gas feedstock = upstream emission factor (13 g $CO_2$/MJ) + CO2 emission factor (50 g $CO_2$/MJ). Emission factor of natural gas combustion = upstream emission factor (13 g $CO_2$e/MJ) + combustion emission factor (55 g $CO_2$e/MJ). See Annex 1, Section 1.1 for natural gas emission factors

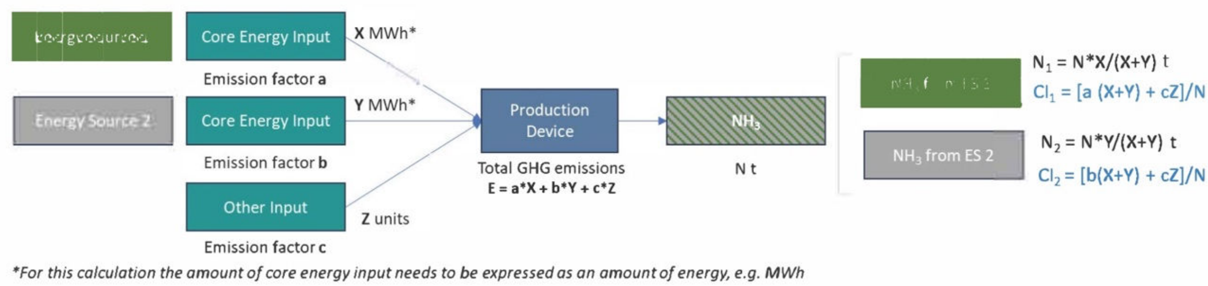
** Emission factor of natural gas = upstream emission factor (13 g $CO_2$/MJ) + CO2 emission factor (55 g $CO_2$/MJ). See Section 8.1 for natural gas default emission factor

1 MWH = 3.600MJ, therefore 68g $CO_2$e/MJ = 3600*68g $CO_2$E/MWH = 244,800g $CO_2$/MWH = 0.245t $CO_2$e/MWH

## Ammonia from Multiple Core Energy Sources

When ammonia is produced using hydrogen generated from multiple core energy sources, the quantity of ammonia considered to be produced from each core energy source (ES) and its corresponding carbon intensity shall be calculated as shown in Figure 4.

*Figure 4: Quantity and carbon intensity of ammonia produced from multiple core energy sources*




In the above figure, amount of ammonia from energy source 1 (ES 1) is calculated by:

$$N_1 = N * X/(X + Y)$$

Where:

$N_1$ amount of ammonia produced from ES 1
$N$ total amount of ammonia produced
$X$ amount of core energy input for ES 1

$Y$ amount of core energy input for ES 2

Carbon intensity assigned to $NH_3$ from ES 1 is calculated as emissions assigned to ammonia from ES 1 divided by quantity of ammonia from ES 1:

$$CI_1 = \left[a * X + \frac{X}{X+Y} * (c * Z)\right] / N_1$$

$$CI_1 = \left[a * X + \frac{X}{X+Y} * (c * Z)\right] / [N * \frac{X}{X+Y}]$$

$$CI_1 = [a(X+Y) + (c * Z)]/N$$

Amount of $NH_3$ from ES 2 is calculated by:

$$N_2 = N * Y/(X+Y)$$

Where:

$N_2$ amount of ammonia produced from ES 2

Similarly, as for the carbon intensity assigned to ammonia from ES 1, the carbon intensity assigned to ammonia from ES 2 is:

$$CI_2 = \left[b * Y + \frac{Y}{(X+Y)} * (c * Z)\right] / N_2$$

$$CI_2 = [b(X+Y) + (c * Z)]/N$$

## Allocation of Emissions to Multiple Co-Products

This section covers the case of co-production of ammonia together with co-products such as steam. The share of emissions assigned to co-products is determined as described below, in application of ISO 14067[3].

First, the production process needs to be subdivided into sub-processes, to identify which inputs and intermediate products contribute to defining the carbon intensity of co-products. After subdivision, relevant emissions related to the considered subprocess need to be divided between the used outputs

[3] ISO 14067: *Greenhouse gases — Carbon footprint of products — Requirements and guidelines for quantification*.

of said subprocess, in a procedure called allocation. Relevant emissions are those of inputs at the input gate of the subprocess as well as the subprocess' own process emissions. In the case of multiple subprocesses, allocation shall start with subprocesses that are most upstream.

Emissions shall be distributed between coproducts based on how the upstream and process emissions change when the quantity of just one product output is changed, i.e., keeping the quantities of all the other product outputs constant.

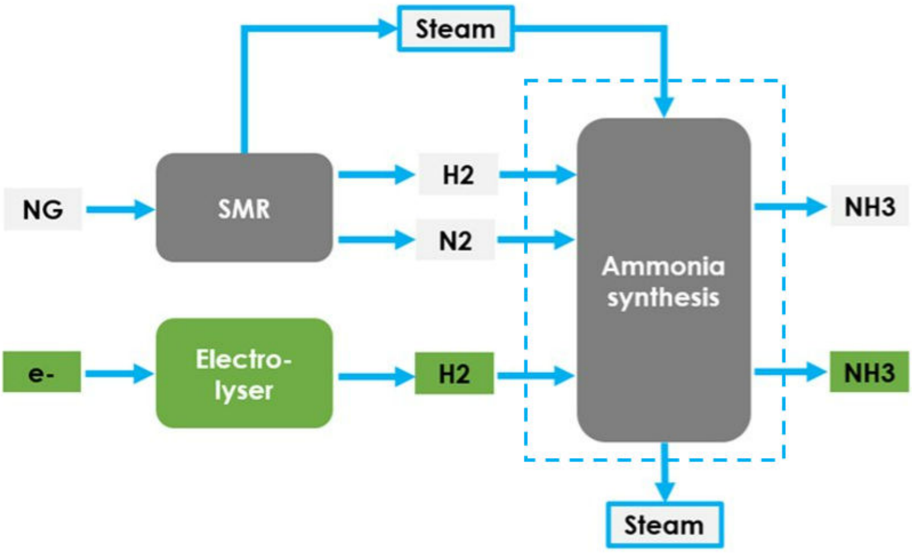
When steam generated from process heat is exported, upstream and process emissions of the process shall be allocated to the steam considering net steam enthalpy consumption divided by the default conversion efficiencies of 90% and 98%, as specified in section 4.4, to account for losses in a gas boiler or heat exchanger, respectively, for transferring the process heat to the steam. Alternatively, allocation may be performed in proportion to the energy content of the co-products, which for steam is the net enthalpy exported with the steam.

## Allocation of Emissions to Steam in Hybrid Ammonia Plants

This section discusses hybrid ammonia plants, which produce ammonia made from both natural gas-based steam methane reforming (SMR) and water electrolysis within a single integrated facility.

The production process begins by compressing syngas, a mixture composed of hydrogen derived from both the SMR and electrolysis processes, as well as nitrogen from the secondary reformer. Energy for this process, in the form of high-grade steam, primarily comes from the SMR and is utilized in the ammonia synthesis unit. During the synthesis of ammonia, heat is generated which is then converted into medium-grade steam. This steam is either rerouted back to the SMR for reuse or directed elsewhere within the facility. For a clearer understanding, refer to Figure 5, which provides a simplified depiction of this process.

*Figure 5: Simplified process scheme of a hybrid ammonia plant, highlighting steam energy flows*




Regardless of the core energy source of the hydrogen, the carbon intensity of the produced ammonia includes GHG emissions related to the energy used by the ammonia synthesis unit, of which net steam enthalpy consumed constitutes a major part.

The contribution of steam to the carbon intensity of the ammonia produced, is determined (i) by the net consumption of steam enthalpy and (ii) the carbon intensity assigned to steam energy entering and leaving the synthesis unit.

Quantification of the net consumption of steam enthalpy should, when possible, be performed by measuring overall steam input and output flows to and from the synthesis unit along with the relevant steam properties (pressure and temperature). If this is too difficult or resource intensive, the steam enthalpy balance may be calculated from plant equipment specifications.
In such a case, the net steam balance in the ammonia backend may be calculated from the theoretically required mechanical energy for ammonia syngas compression with an isentropic efficiency of 60%, as well as energy required for converting the available steam into mechanical energy, based on the specifications of the installed equipment.

A carbon intensity must be assigned to both the steam supplied to and exported from the synthesis unit, as indicated in Figure 5. The carbon intensity of the steam supplied from the SMR or exported from the synthesis unit shall be determined as specified in section 4.4.

# 5 Carbon Intensity of Inputs

## 5.1 Hydrogen

The carbon intensity of hydrogen from an external source will be supplied from a recognized certification system. Recognized hydrogen certificate programs found in Annex 1: Default Emission Values and Acceptable Certification Schemes. Hydrogen production certificates must be retired for the consumed quantity of hydrogen. The hydrogen production certificate specifies the carbon intensity of the hydrogen, which is to be applied in the calculation of the ammonia carbon intensity. If the supplier of the hydrogen has not pursued certification, it is mandatory that the audit process of the ammonia plant additionally cover the hydrogen production and transport to the ammonia production facility.

When hydrogen is produced within an integrated process in the ammonia production facility, there is not a requirement for retiring a Hydrogen Production Certificate. In such cases, the carbon intensity (CI) of hydrogen is calculated using the methodology developed by CertifHy[4], as detailed in Section 3.

## 5.2 Natural Gas, RNG and RSG

The carbon intensity of natural gas, Renewable Natural Gas (RNG) or Responsibly Sourced Gas (RSG) shall be based on information from its supplier. For natural gas, if the supplier does not specify a CI, operators must apply a default value listed Annex 1: Default Emission Values and Acceptable Certification Schemes. To claim a lower CI of methane when using natural gas, RNG, or RSG, certificates found in Annex 1. The CI must be retired for the consumed quantity. The methane certificates must have been issued within the country, i.e. U.S. or Canada, of consumption.

## 5.3 Electricity

The carbon intensity of electricity shall include lifecycle emissions from the electricity supply system and emissions occurring during generation, including any energy losses. The use of renewable electricity and its corresponding low emission factor may be claimed through retirement of unbundled Renewable Energy Certificates (RECs) or purchase of a Power Purchase Agreement (PPA) with bundled RECs, equivalent to the quantity of consumed renewable electricity. For the quantity of contractually purchased renewable electricity, a carbon intensity of zero may be applied in the ammonia CI calculation. RECs must be cancelled following the guidelines provided by the REC scheme within one year of the consumption of the claimed electricity, i.e., annual matching. The geographical scope of RECs is restricted to the regional domain in which the applicable tracking system is active.

[4] CertifHy: CertifHy-SD Carbon Footprint Calculation, 2023.

RECs must also be cancelled for production plants that have a direct connection to the renewable energy production asset. Any electricity consumption that is not covered within the quantity of cancelled RECs shall apply the regional residual mix factor for assigning the CI, as published by regional certificate tracking systems through eGrid[5].

If the regional residual mix factor is not available, the regional grid average emission factor may be applied.

## 5.4 Steam

The emissions assigned to steam used as an input should be consistent with allocation to the co-products of the process from which the steam originates, considering the steam as one of the co-products, see section 4.4.

## 5.5 Other Inputs

The carbon intensity of other inputs, which are not specifically mentioned above, shall be based on the CI provided by the product supplier.

[5] United States Environmental Protection Agency: eGrid Data Explorer; 2023.

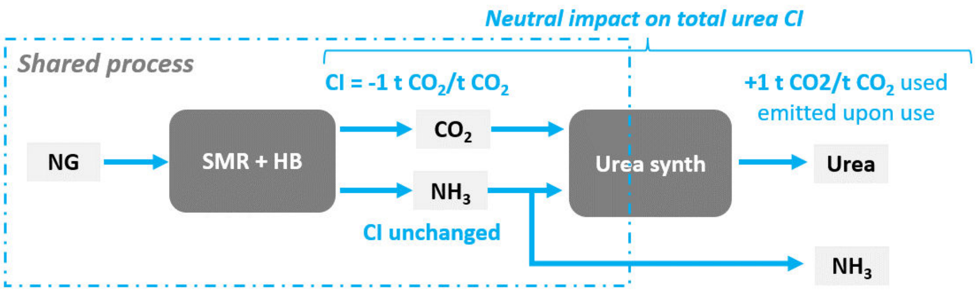
# 6 Carbon Capture Utilization & Storage

This section describes how credit from carbon capture in ammonia production is assigned for the utilization and storage of carbon. Additionally, the requirements for geological storage of carbon dioxide are laid out.

## 6.1 Allocation of Credit for Carbon Capture and Utilization

The reduction of GHG emissions resulting from the capture of carbon dioxide shall be assigned to the user of the captured carbon dioxide. Captured carbon dioxide is assigned a carbon intensity of -1 t $CO_2$e/t at the gate of the capture process, reflecting that the carbon dioxide is considered to have been previously removed from the atmosphere. As a result, the use of the carbon dioxide later released to the atmosphere in the downstream product's lifecycle has a neutralizing impact on its CI. Evidence of clear allocation and ownership of environmental attributes is required to claim credit for carbon capture and utilization.

*Figure 6: Carbon credit allocation for captured carbon used for co-production of ammonia and urea*




The allocation of emissions reductions for carbon capture is illustrated using the example of co-production of ammonia and d with carbon capture. In this process, carbon is captured at the ammonia production step, i.e., carbon dioxide and ammonia are co-products. According to the allocation principle mentioned earlier, carbon dioxide is given full credit for capture and leaves the ammonia production step with a negative CI. The ammonia CI remains unchanged compared to a production setup where carbon capture is not included. Figure 6 illustrates how carbon dioxide used for the synthesis of urea has a neutral impact on the urea CI.

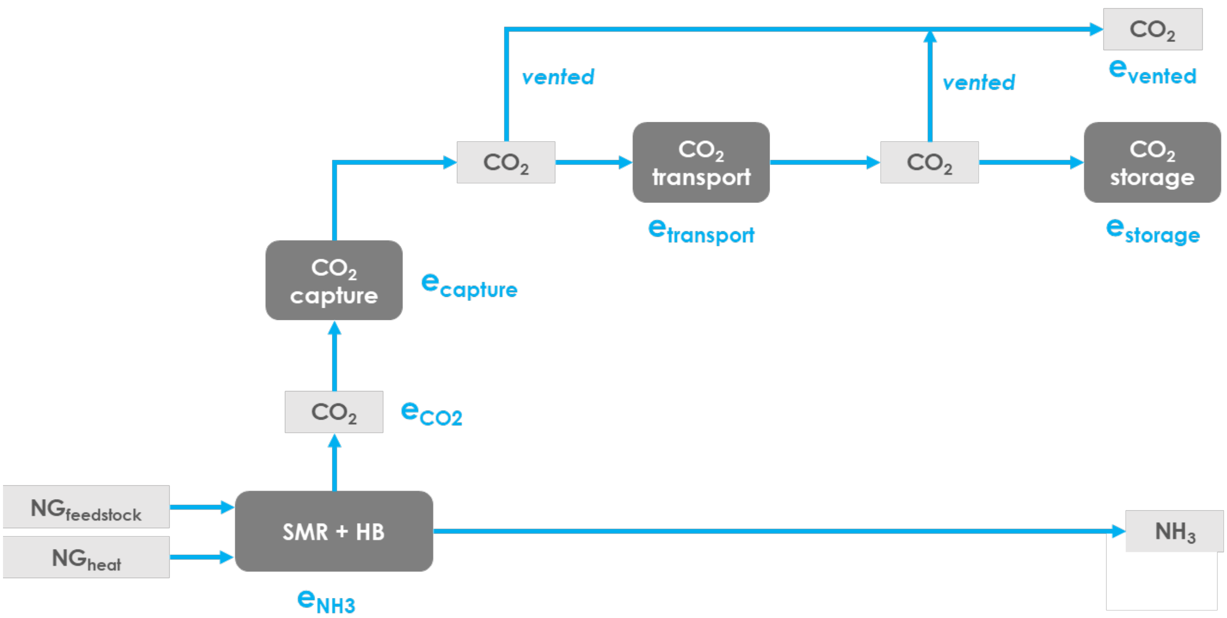
## 6.2 Allocation of Credit for Full and Partial CCS

Carbon dioxide capture and geological storage (CCS) includes capturing carbon dioxide from industrial installations, transporting it to a storage site, and injecting it into a suitable underground geological formation for permanent storage. Emissions related to these three steps of CCS must be accounted for when assigning credit to co-products of a carbon capture process.

The credit for captured and stored carbon is assigned to co-products of the process at which carbon is captured. The captured carbon is credited to co-product(s) by allocating a negative contribution to the CI of co-product(s) proportional to the quantity of captured and stored carbon. Any emissions and losses occurring in the transport and storage of $CO_2$ must be assigned to the co-products receiving the emissions credit. Credit is only eligible if the requirements for geological storage of carbon dioxide, in section 6.4, are met.

The allocation of credit for CCS is illustrated using the example of ammonia from steam methane reforming (SMR) with CCS. The process emissions from the SMR step are captured and geologically stored. The CI of ammonia receives the credits for the quantity of captured carbon, eCO2, in Figure 7. Emissions from the capture, transport, and storage of carbon, including any vented carbon emissions, are assigned to the ammonia; see Figure 7.

*Figure 7: Allocation of credit for CCS, example of SMR and Haber Bosch process*




It should be noted that for most SMR plants, the CO2 capture process is embedded in the SMR, and $e_{capture}$ may be zero. The CI of ammonia produced with verifiable $CO_2$ storage receives an emissions reduction and is calculated as follows,

$$CI_{NH3} = \frac{e_{input} + e_{process} - e_{removal}}{Q_{NH3}}$$

Where

$CI_{NH3}$ carbon intensity of ammonia (t $CO_{2eq}$/t)

$e_{input}$ GHG emissions from the supply of inputs, i.e., well-to-supply-gate emissions *related to the inputs* (t $CO_{2eq}$)

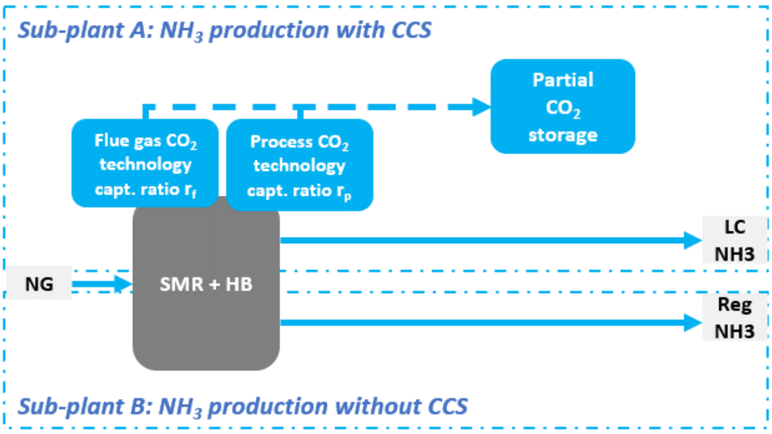
$e_{process}$ GHG emissions from the production of ammonia, including process side or internal and flue gas emissions (t $CO_{2eq}$)

$e_{removal}$ Net GHG emissions permanently sequestered, considering emissions from $CO_2$ capture, transport, storage, and losses (t $CO_{2eq}$)

$Q_{NH3}$ Quantity of ammonia produced (t)

In the case that only a portion of the carbon dioxide (either process or combustion) that could technically be captured by the technology is actually captured and stored, a 'virtual plant splitting' approach may be used. The plant can be virtually split into sub-plant A, which includes the implemented capture solution, and sub-plant B, which does not apply CCS, as illustrated in Figure 8. Splitting of the plant allows to assign the emissions reduction from CCS to the ammonia production of sub-plant A, while the ammonia produced at sub-plant B does not receive a credit.

*Figure 8: Allocation of carbon credit for partial CCS*




The CI, $CI_{LC\ NH3}$, and quantity, $Q_{LC\ NH3}$, of low-carbon ammonia from (virtual) sub-plant A may be calculated applying actual production capacity data as follows.

$$CI_{LC\ NH3} = \frac{e_{LC\ input} + e_{LC\ process} - e_{removal}}{Q_{LC\ NH3}}$$

$$Q_{LC\ NH3} = \frac{e_{stored}}{e_{captured}} \cdot Q_{NH3}$$

Where

$e_{LC\ input}$ GHG emissions from the supply of inputs, i.e., well-to-supply-gate emissions *related to the inputs* (t $CO_{2eq}$) from sub-plant A

| | |
|---|---|
| $e_{LC\ process}$ | GHG emissions from the production of ammonia (t $CO_{2eq}$) from sub-plant A |
| $e_{stored}$ | Carbon dioxide stored |
| $e_{captured}$ | Carbon dioxide captured and available for storage; defined as sum of $CO_2$ removed from syngas ("process $CO_2$") and $CO_2$ captured in flue gas, only considering $CO_2$ streams technically connected to the CCS infrastructure (t $CO_{2eq}$). |
| $Q_{NH3}$ | Quantity of ammonia produced (t) |

The quantity of regular ammonia, $Q_{Reg\ NH3}$, is determined as,

$$Q_{Reg\ NH3} = Q_{NH3} - Q_{LC\ NH3}.$$

The carbon intensity of the remaining (regular) ammonia production is calculated as,

$$CI_{Reg\ NH_3} = \frac{e_{input} + e_{process}}{Q_{NH_3}}$$

In the case that multiple ammonia production plants with CCS capabilities are connected to the same $CO_2$ network, it must be specified to which ammonia production plant the stored $CO_2$ is assigned. The operator shall indicate the order of plants to which storage is assigned, which shall not be changed more often than once per year. The assigned $CO_2$ storage shall never exceed the quantity of $CO_2$ captured at the specified plant.

## 6.3 Allocation of Credit for Carbon Capture and Storage (CCS) in the Case of Co-Production of Ammonia and Urea

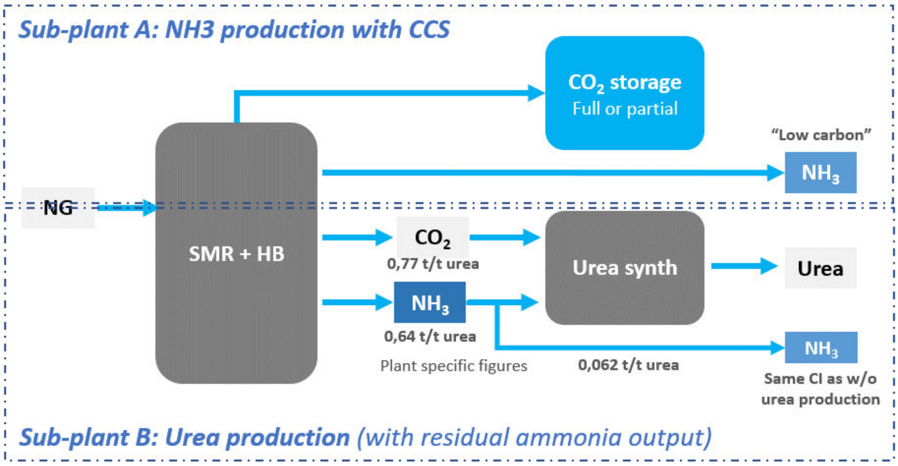
This section describes the allocation of credits for carbon capture and storage for plants that co-produce ammonia and urea. In such cases, the plant may be split into two sub-plants, called A and B in the following, as shown in figure 9. Sub-plant A includes the CCS technology and produces low-carbon ammonia. The credit for carbon storage is fully assigned to the low-carbon ammonia from this sub-plant. A credit for CCS shall be assigned when the requirements for carbon storage, as laid out in section 4.4 are fulfilled. Sub-plant B utilizes ammonia along with part of the captured carbon dioxide for urea production, with some residual conventional ammonia corresponding to ammonia co-produced with the used carbon dioxide but not used by the process.

The CI for Ammonia with CCS from Sub-Plant A follows Paragraph 4.2.

The CI of the ammonia from sub-plant B remains the same as in the case where there is no CCS. The carbon dioxide utilized in sub-plant B carries the credit for carbon dioxide capture, resulting in its use having a neutral impact on the total CI of the urea.

The principles discussed in this section apply only to the CI calculation for ammonia and are not intended to limit the use or allocation of the ammonia product generated within these subplants, including for use in urea production.

*Figure 9: Allocation of credit for carbon capture and utilization*




## 6.4 Requirements for Geological Carbon Storage

To reduce the carbon intensity of ammonia, geological carbon dioxide storage, including Enhanced Oil Recovery, needs to be performed following a regulatory framework setting out the requirements for the safe and long-term storage of carbon dioxide. Users need to comply with their particular regulations and may need to provide measurement, reporting, and verification plan requirements (see section 8).

For example, the United States Internal Revenue Code Section 45Q tax credit defines guidelines for carbon capture and sequestration (CCS) – see the United States Federal Register document *86 FR 4728 - Credit for Carbon Oxide Sequestration*. This document defines the final regulations that guide the credit for carbon sequestration.

# 7 Greenhouse Gas Emissions of Waste Disposal

In case the ammonia production process generates waste material, the emissions occurring from the disposal of this waste process must be included in the carbon intensity of the ammonia. These emissions include the processing and transport of the waste.

# 8 Cut-Off Criteria

When evaluating the environmental performance of energy systems through LCA (Life Cycle Assessment) it is important to include a materiality threshold to avoid unjustified efforts in quantifying total emissions beyond the agreed level of accuracy. A cut-off criterion of a cumulative of 2.5 percent specifies which elements of the carbon emission assessment may be excluded from the total carbon intensity of the ammonia.

The carbon intensity of ammonia shall cover all processes and material flows within the system. Some elements contributing to the carbon intensity may, however, be excluded based on insignificant contributions in terms of material amount, energy flow or greenhouse gas emissions. This materiality can be set as a percentage of the total ammonia CI. Emissions associated with process catalyst material do not need to be quantified.

For the purpose of this certification scheme, a threshold of 2.5 % of the total ammonia carbon intensity, must not be exceeded by the sum of all emissions that may be excluded from the carbon intensity greenhouse gas emissions[6]..

[6] Corresponding to the lowest priority contribution of inputs, class "*E: not important, negligible influence*", defined by ISO 14044:2006(en), Environmental management — Life cycle assessment — Requirements and guidelines; July 2006.

# 9 Data Quality Requirements

The data used for calculating the ammonia's CI is subject to quality requirements to ensure adequate accuracy of the quantification, based on a Data Quality Rating (DQR) system. A higher quality rating is requested for data pertaining to the 'Most Relevant Processes' which are those that collectively contribute to at least 80% of the carbon intensity of ammonia.

The DQR system evaluates separately the quality of primary data ($DQR_{Primary}$) and secondary data ($DQR_{Secondary}$). Primary data, also referred to as process-specific data, is data directly measured or collected at a specific facility. Secondary data is data from literature, scientific papers, industry average life cycle data, industry association reports, government statistics or other relevant sources.

The level of data quality required depends on whether the data pertains to the most relevant processes and whether the process is run by the company conducting the calculation as described in Table 2. The level of quality specified in this table shall be met as far as reasonably possible.

*Table 2: Data Quality Requirements based on Data Access & Process Relevance*

| Access to data | Data pertaining to Most Relevant Processes | Data pertaining to other processes |
|---|---|---|
| **Situation 1:** The process is run by the company conducting the calculation. | Production Batch specific data rated as 'Good' | Process specific data rated as 'Fair'<br>*OR*<br>Secondary data rated as 'Good'. |
| **Situation 2:** The process is not run by the company conducting the calculation, but the company has access to process specific information. | Process specific data rated as 'Good' | Process specific data rated as 'Fair'<br>OR<br>Supply chain specific data for transport and electricity rated as 'Fair' |
| **Situation 3:** The process is not run by the company conducting the calculation and the company does not have access to process specific information. | Supply chain specific data for transport and electricity rated as 'Good'<br>*OR*<br>Secondary data rated as 'Good'<br><br>Note: Process specific data is required for externally sourced hydrogen and biomethane | Supply chain specific data for transport and electricity rated as 'Fair'<br>*OR*<br>Secondary data rated as 'Fair |

The criteria for rating the quality of primary data and secondary data as "Good" or "Fair" are described in sections 7.1 and 7.2, respectively.

## 9.1 Primary Data

For primary data, data quality is assessed with regards to the following two characteristics:

1. **Precision/Accuracy ($PA$)**: This is a measure of the accuracy and reliability of the data. PA assesses the extent to which the data points are measured or calculated with precision and verified, thus ensuring the accurate representation of the company's operations.
2. **Time-Related Representativeness ($TIR_{Primary}$)**: This is a measure of how recent the data is and if it accurately represents the company's current operations.
   This criterion does not apply to batch specific primary data (since batch specific data is by definition representative of the situation in the batches time period).

Primary data quality is rated as "good" or "fair" if it achieves a "good" or "fair" rating for the above applicable characteristics, following the criteria provided by Table 3.

*Table 3: Primary Data Quality Rating Index*

| Primary Data Quality Rating Index | | | |
|---|---|---|---|
| **Score** | **Rating** | **Precision/Accuracy ($PA$)** | **Time-Related Representativeness ($TIR_{Primary}$)** |
| 3 | Good | The data point(s) is measured or calculated, internally verified, and its plausibility is checked by a reviewer. | The data point(s) refers to an annual administration period not older than two years, |
| 2 | Fair | The data point(s) is either measured, calculated, or referenced from literature without a plausibility check by a reviewer. | The data point(s) refers to an annual administration period, not older than four years, |
| 1 | Poor | Above conditions not met | Above conditions not met |

In addition, the accuracy of measured data shall as far as reasonably possible target +/- 2.5%.

## 9.2 Secondary Data

Default values, such as those used for combustion emissions, upstream emissions for supply of natural gas or utilities such as nitrogen, fall under the category of secondary data. Further discussion of default values can be found in document "Ammonia Carbon Intensity Calculation Methodology Annex" section 1.1.

For secondary data, data quality is assessed with regards to the following three characteristics:

1. **Technological Representativeness ($TR$)**: This measures how well the data reflects the specific technology, or technologies used within the company.
2. **Geographical Representativeness ($GR$)**: This assesses how well the data represents the specific geographical location or locations of the company's operations.
3. **Time-Related Representativeness ($TIR_{Secondary}$)**: This evaluates how recent the data is and if it accurately reflects the company's current operations.

Secondary data quality is rated as "good" or "fair" if it achieves a "good" or "fair" rating for all the above characteristics, following the criteria provided by Table 4.

*Table 4: Secondary Data Quality Rating Index*

| Secondary Data Quality Rating Index | | | | |
|---|---|---|---|---|
| **Score** | **Rating** | **Time-Related Representativeness ($TIR_{Secondary}$)** | **Technology Representativeness ($TR$)** | **Geographical Representativeness ($GR$)** |
| 4 | Excellent | The CI calculation utilizes data within the time validity of the dataset and does not extend more than two years beyond that time validity. | The CI calculation utilizes technology data representative of the exact or included technologies in the scope of the dataset. | The CI calculation utilizes data representative of the country or geographical region for which the dataset is valid. |
| 3 | Good | The CI calculation utilizes data no later than 4 years beyond the time validity of the dataset. | The CI calculation uses technologies partly representative of those included in the dataset's scope. | The CI calculation utilizes data representative of one of the regions for which the dataset is valid. |
| 2 | Fair | The CI calculation utilizes data no later than 6 years beyond the time validity of the dataset. | The CI calculation uses technologies that are somewhat representative of those included in the dataset's scope. | The CI calculation utilizes data that represents a country not included in the geographical regions for which the dataset is valid, but there are estimated sufficient similarities based on expert judgement. |
| 1 | Poor | The CI calculation utilizes data more than | The CI calculation utilizes technologies | The CI calculation utilizes data representative of a |

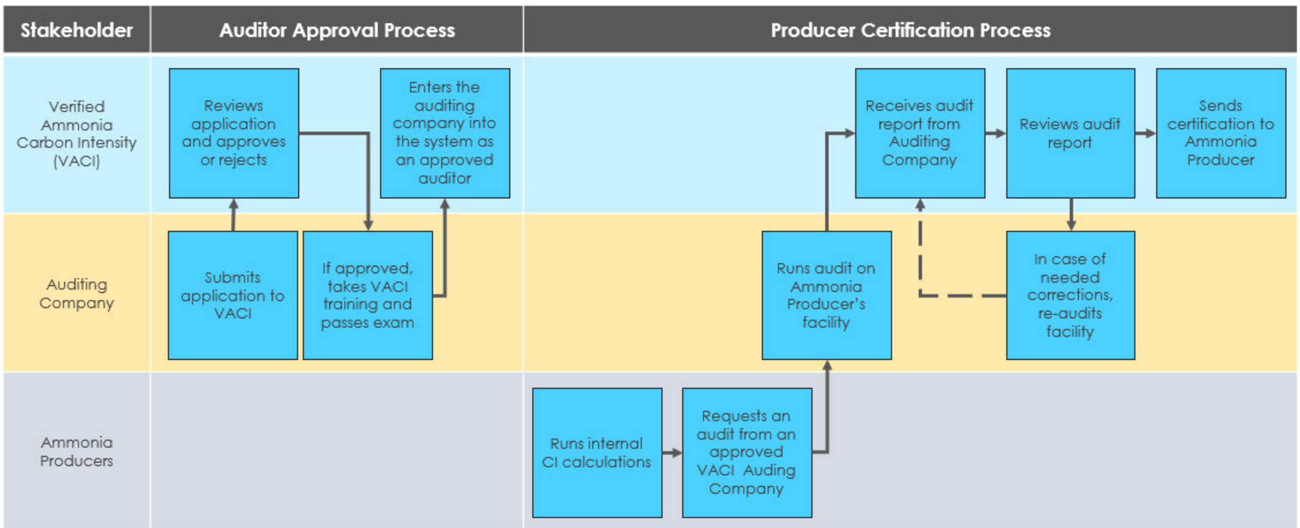
| Secondary Data Quality Rating Index | | | | |
|---|---|---|---|---|
| **Score** | **Rating** | **Time-Related Representativeness ($TIR_{Secondary}$)** | **Technology Representativeness ($TR$)** | **Geographical Representativeness ($GR$)** |
| | | 6 years after the time validity of the dataset, or the time validity is not specified. | not representative of those included in the scope of the dataset. | different country than the one for which the dataset is valid. |

# 10 Verification

This section describes the verification process under the TFI certification scheme.

Production plants are audited every 12 months, and the audit will verify the CI calculations for the batches generated by the plant operator. Annex 3 provides examples of the data and documentation to be verified by the auditor. The audit covers the aspects and related requirements described below. The plant operator accepts responsibility for preparing the information required for the audit.

*Figure 10. Verification Process*




## 10.1 Management System

The management system at the production facility must ensure that employees have been assigned the task of implementing requirements at critical control points and trained appropriately.

Furthermore, the plant operator must:

- have a documentation management system
- have an auditable system for safekeeping and reviewing all evidence they rely on for claiming supply of product certified under the TFI methodology;
- keep all evidence necessary to comply with the TFI scheme for a minimum of 5 years.
- The ammonia producer must provide a Measurement, Reporting, and Verification plan addressing the following key points:
    - Plant boundary
    - Physical infrastructure, activities, technologies, and processes of the Plant

  - GHGs, sources, and sinks within the project boundary
  - Frequency of data acquisition
  - Methodologies, algorithms, and calculations that will be used to generate estimates of emissions and emission reductions (Application of RECs, waste heat recovery, etc.)
  - Frequency of instrument field check and calibration activities
  - Sources of data activity used in calculations
  - Role of individuals performing monitoring activities
  - QA/QC procedures for data acquisition and meter calibration activities
  - Procedures to demonstrate legal compliance
  - Project-specific conformance with the Methodology
  - Environmental attributes (Ownership)

### 10.2 Qualification & Training of Employees

The corporation must ascertain that all personnel involved in the calculation of the carbon intensity in ammonia production are suitably qualified. These individuals must have the necessary training, education, skills, and experience relevant to greenhouse gas accounting.

### 10.3 Verification of CI Calculation

The plant operator must provide auditors with all the relevant and up to date information concerning the calculation of actual GHG emissions, in advance of the planned audit. That information shall include input data and any other relevant evidence, information on the emission and conversion factors and standard values applied and their reference sources, GHG emission calculations and evidence relating to the application of GHG emission saving credits.

The verification process aims to ensure that the ammonia CI is calculated correctly. This includes verification of the following items, as seen in Figure 11.

- upstream and combustion/process emission factors of input materials
- input and output quantities (process emissions).

- correct application of the specified allocation approaches, assignment of credit for geological storage of CO2, and virtual plant splitting when relevant.

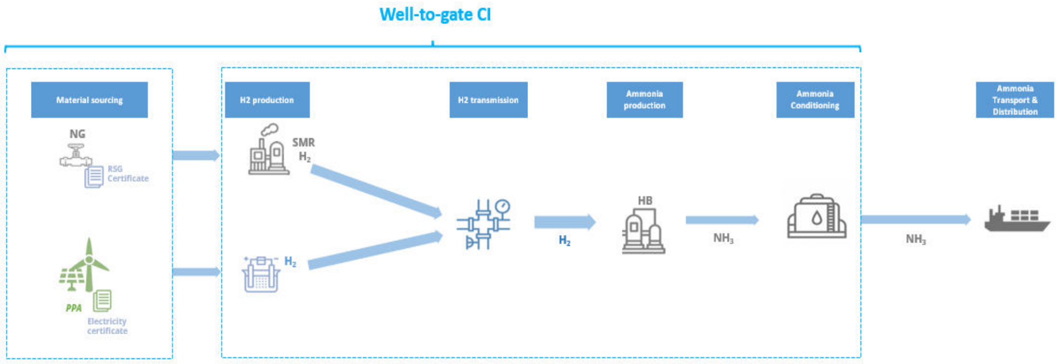



*Figure 11: Verification of GHG emissions along the ammonia supply chain*

The relevant documents that must be provided to the auditor are:

- **Greenhouse gas calculation sheet**: An excel sheet (or equivalent calculation software) providing the details on the calculation of the ammonia CI including all data inputs regarding the CIs (Carbon Intensity) of input materials and input and output quantities.
- **CI of input materials**: The CIs of input materials are verified through statements provided from input material suppliers. For sustainable or low-carbon inputs, such as electricity, RNG, RSG or hydrogen, certificates verifying its CI must be provided.

# 11 Appendix List

Annex 1: Default Emission Values and Acceptable Certification Schemes

# Annex 1: Default Emission Values and Acceptable Certification Schemes

## Table of contents



## List of tables

# 1. Scope

The annex will be updated periodically to reflect updates made by the TFI as part of the Carbon Footprint Methodology.

## 1.1 Default Carbon Intensity Values

Default values may be taken from the following approved list of databases:

- Ecoinvent
- GREET Model (please specify year of GREET model data)

Additionally, default values for input materials may be chosen from Table 1. The default values provided are subject to annual revision.

*Table 5 Default values for carbon intensities of inputs*

| Input | Carbon intensity | | Source |
|---|---|---|---|
| Natural gas | Combustion | *56.49 g $CO_2e$/MJ LHV | GREET model and Table-C1 to Subpart C of Part 98 |
| | Feedstock | 50.29 g g $CO_2$/MJ LHV | |
| | Upstream supply | *13.02 g $CO_2e$/MJ LHV | |
| Electricity | United States Environmental Protection Agency: eGrid Data Explorer<br><br>Canadian National Inventory Report<br>ECCC Data Catalogue | | United States Environmental Protection Agency: eGrid Data Explorer<br><br>Canadian National Inventory Report<br>ECCC Data Catalogue |
| Nitrogen | TBD | | |

**Carbon intensities represent GREET 2022 data. If using a value from a different year, please ensure the value for that year and data is provided*

## 1.2 Combustion Emissions

Hydrocarbon combustion emissions calculation:

- Used in all cases where hydrocarbons used for combustion result in flue gas emissions to the atmosphere. Emissions from these streams shall be calculated using defaults or the Environmental Protection Agency

(EPA) Air Emissions Factors. Examples are energy for reformer firing, auxiliary boiler use, gas turbine use, process heater use, start-up heater use, etc.

Hydrogen, hydrogen-rich gas, and off gas stream combustion emissions calculations:

- Used in all cases where hydrocarbons used for combustion result in flue gas emissions to the atmosphere. Emissions from these streams shall be calculated using the Environmental Protection Agency (EPA) Air Emissions Factors. Examples include purge gas recovery, NOx abatement, etc.

## 1.3 Process Nitrogen Carbon Intensity Calculations

Process nitrogen is only used as a feedstock in the production process (e.g., ammonia). Imported nitrogen for utility use, such as for inert gas blanketing needs, purging of vessels, etc., is not included.

Process nitrogen imports (nitrogen for ammonia production process consumption) are based on its actual product carbon intensity used for production and delivery to the plant.

The contribution to the carbon intensity from methane emissions will be included and calculated using EPA sub part 98 sub part C methodology.

## 1.4 Emissions Associated with the Cooling Water System

The basis for cooling water is that the energy for producing and pumping of all cooling water is included in the plant's energy usage. Where a plant imports cooling water (from a cooling tower, river water, sea water, etc.) the pumping energy and cooling fan energy (for cooling towers) is added as an energy debit. Actual energy usage is used if known.

If the actual energy is unknown or is not included in the plant's energy allocation, the following estimates are used:

- The pumping energy is based on using an 85% efficient single-stage, double suction centrifugal pump. Coupled with a large 96% efficient electric motor, the overall pumping efficiency is 82% (34 kWh/bar/1000 m3 water); and
- The energy for cooling tower fan operation is 44 kWh/1000 m3 water.

The total energy per volumetric unit of cooling water is converted to carbon emissions based upon the motive force of the pumps/fans (i.e., electricity emissions factor or steam emissions factor)

## 1.5 Emissions From Boiler Feed Water (BFW) Imports/Exports

- The actual electrical pumping energy, or the steam usage in a steam turbine, is used if known.
- If unknown, the pumping energy is estimated using a multi-stage, centrifugal pump with 65% efficiency. Coupled with a large 96% efficient electric motor, the resulting pumping efficiency is 62% (45 kWh/bar/kT of BFW).
- The actual steam required to generate the BFW is included (and converted to an energy value as in steam section) if known; and
- If unknown, the energy is estimated based on the BFW temperature using 4.15 kJ (LHV)/C°/kg and a base (feed) temperature of 15 °C.
- The total energy per volumetric unit of BFW is converted to carbon emissions based upon the motive force of the pumps/fans (i.e., electricity emissions factor or steam emissions factor)

## 1.6 Table of TFI Recognized Certification System

TFI will recognize other certification systems for data inputs, as listed in table 2. Future recognized certification systems will be approved through the Verified Ammonia Carbon Program management system.

*Table 6 Recognized certification systems for inputs.*

| Certification System | Product |
|---|---|
| M-RETs RTC | RNG |
| Green-e renewable fuels | RNG |
| MiQ | RSG |
| Project Canary | RSG |
| CertifHy Non-Governmental Certificate | Hydrogen |
| CertifHy | Hydrogen |
| ISCC | Hydrogen |
| ISCC+ | Hydrogen |
| Green-e RECs | Electricity |
| M-RETs RECs | Electricity |